

# Spaceflight Ground Support Equipment Reliability & System Safety Data

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## *SUMMARY & CONCLUSIONS*

Presented were Reliability Analysis, consisting primarily of Failure Modes and Effects Analysis (FMEA), and System Safety Analysis, consisting of Preliminary Hazards Analysis (PHA), performed to ensure that the CoNNeCT (Communications, Navigation, and Networking re-Configurable Testbed) Flight System was safely and reliably operated during its Assembly, Integration and Test (AI&T) phase. A tailored approach to the NASA Ground Support Equipment (GSE) standard, NASA-STD-5005C,[1] involving the application of the appropriate Requirements, S&MA discipline expertise, and a Configuration Management system (to retain a record of the analysis and documentation) were presented. Presented were System Block Diagrams of selected GSE and the corresponding FMEA, as well as the PHAs. Also discussed are the specific examples of the FMEAs and PHAs being used during the AI&T phase to drive modifications to the GSE (via “redlining” of test procedures, and the placement of warning stickers to protect the flight hardware) before being interfaced to the Flight System. These modifications were necessary because failure modes and hazards were identified during the analysis that had not been properly mitigated. Strict Configuration Management was applied to changes (whether due to upgrades or expired calibrations) in the GSE by revisiting the FMEAs and PHAs to reflect the latest System Block Diagrams and Bill Of Material. The CoNNeCT flight system has been successfully assembled, integrated, tested, and shipped to the launch site without incident. This demonstrates that the steps taken to safeguard the flight system when it was interfaced to the various GSE were successful.

## *1 INTRODUCTION*

The National Aeronautics and Space Administration (NASA) is developing an on-orbit, adaptable, Software Defined Radio (SDR) and Space Telecommunications Radio System (STRS). It will be a test-bed facility on the International Space Station. The CoNNeCT Project’s

operational name for the flight system is the SCaN (Space Communications and Navigation) Testbed. The SCaN Testbed payload will launch on the HTV-III vehicle, and be installed on the Express Logistics Carrier (ELC) 3 at the P3 location on the International Space Station (ISS). Figure 1 shows the SCaN Testbed on the ELC 3 at the third port, P3, location on the International Space Station (ISS). The CoNNeCT flight system will provide an adaptable Software Defined Radio (SDR) / Space Telecommunications Radio Systems (STRS) based facility to conduct a suite of experiments to advance the SDR/STRS Standards, reduce risk by advancing the Technology Readiness Level (TRL) for spaceflight hardware and software, and demonstrate space communication links critical to future NASA missions.

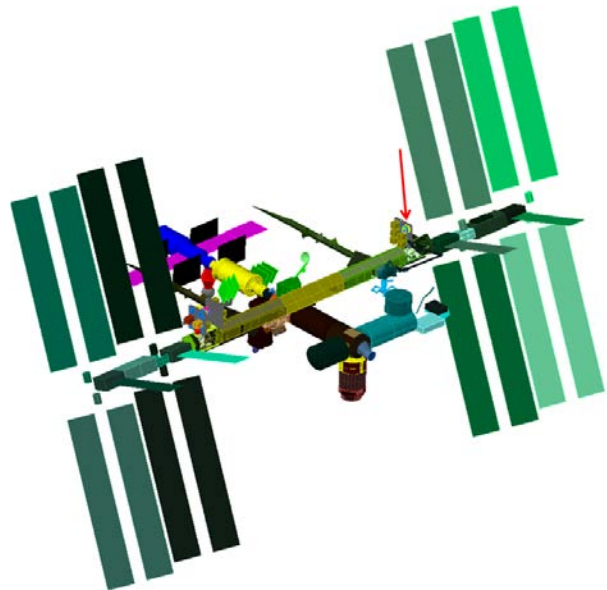


Figure 1: The SCaN Testbed on the ISS

Figure 2 shows the SCaN Testbed integrated onto the ExPRESS Pallet Adapter (ExPA). The ExPA provides the flight system with all its needed interfaces for mechanical

attachment, power, and data to the ISS. It was provided to the CoNNeCT project as a piece of Government Furnished Equipment (GFE) that already had been certified for flight by the ISS. For GSE purposes, ground use of the ExPA is documented in a Memorandum Of Understanding (MOU). The delivery and sustaining engineering for the ExPA was provided by the ISS Vehicle Office (OB), and ensuring its safety and protection during the SCan Testbed's integration and testing was essential.

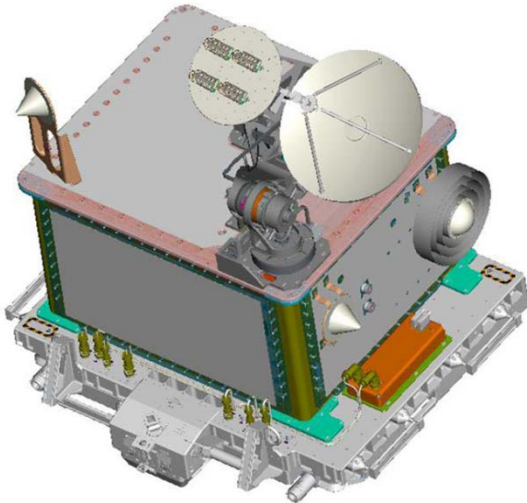


Figure 2: SCAN Testbed integrated onto the ExPA

## 2 GSE CERTIFICATION PROCESS

Prior to the AI&T phase of flight system development, standard NASA-STD-5005C, Standard For The Design And Fabrication Of Ground Support Equipment, was tailored in order to ensure that the design, fabrication, and testing of CoNNeCT's Ground Support Equipment (GSE) was robust, safe, reliable, maintainable, supportable, and cost-effective. This tailoring was based on a criticality review by GRC's Safety and Mission Assurance (S&MA) and Engineering organizations. The tailoring involved the application of the appropriate Requirements, S&MA discipline expertise, and a Configuration Management system (to retain a record of the analysis and documentation). This paper focuses on the S&MA portion of the NASA-STD-5005C tailoring.

### 2.1 The NASA Standard

The Standard For The Design And Fabrication Of Ground Support Equipment, NASA-STD-5005C, states that "This Standard establishes top-level requirements and guidance for design and fabrication of ground support equipment (GSE) to assist National Aeronautics and Space Administration (NASA) space flight programs/projects in providing robust, safe, reliable, maintainable, supportable, and cost-effective GSE." The SCan Testbed employed this Standard to develop its policy on GSE.

It must be noted that the application of this Standard

to NASA space flight programs is at the discretion of the program. This Standard advocates a set of GSE design requirements for NASA programs and projects. This Standard is intended for use in establishing uniform engineering practices and methods and ensuring that essential requirements are included in the design, procurement, and fabrication of GSE used to support the operations of receiving, transportation, handling, assembly, inspection, test, checkout, service, and launch, of payloads at NASA's integration and launch sites.

### 2.2 Tailoring

NASA-STD-5005C itself suggests that it is intended to, and indeed should, be tailored by program specifications to meet specific program, and project needs and constraints based on a criticality review by Safety and Mission Assurance (SMA) according to program and Center procedures. Just such a review was conducted by the SCan Testbed's Chief Engineer and SMA Lead and determined that the following activities will be performed for the certification of GSE.

For CoNNeCT designed GSE:

The technical requirements of 5005C are reviewed and approved by engineering for applicability to the specific piece of GSE.

1. Qualification testing of the GSE is performed and documented
2. The applicable technical requirements are verified by the cognizant/responsible engineer
3. The materials and processes, safety, and quality requirements are verified by the S&MA
4. All certification evidence is compiled into a certification package which is reviewed by Engineering and S&MA for completeness. The package is then entered into the CoNNeCT Configuration Management System.
5. Certified GSE will be tagged with a green label that states it is CoNNeCT certified GSE.

For Commercial Off the Shelf (COTS) GSE:

1. Vendor documentation is evaluated for acceptability from a materials and processes (M&P) and a safety standpoint
2. Vendor test results are evaluated for acceptance
3. A post shipment inspection is performed upon arrival at GRC for packaging and appropriate paperwork
4. A GRC acceptance test is performed.
5. All certification evidence including vendor documentation is compiled into a certification

package which is reviewed by Engineering and S&MA for completeness. The package is then entered into the CoNNeCT Configuration Management System.

6. Certified COTS GSE will be tagged with a green label that states it is CoNNeCT certified GSE.

For in-house (GRC built) GSE Cables:

Certification of the in house cables is completed when the as manufactured cable process plan has been closed with engineering and quality assurance signatures. The cable process plans include and document closure of all cable build and test requirements.

### 3 ASSEMBLY, INTEGRATION, AND TEST

By following the tailored lists of activities for certification, the SCA<sub>n</sub> Testbed was afforded an acceptable level of protection from GSE induced failures, faults, defects, etc. during the AI&T phase of development. Figure 3 shows the SCAN Testbed/ExPA, Radios and Infrastructure Components.

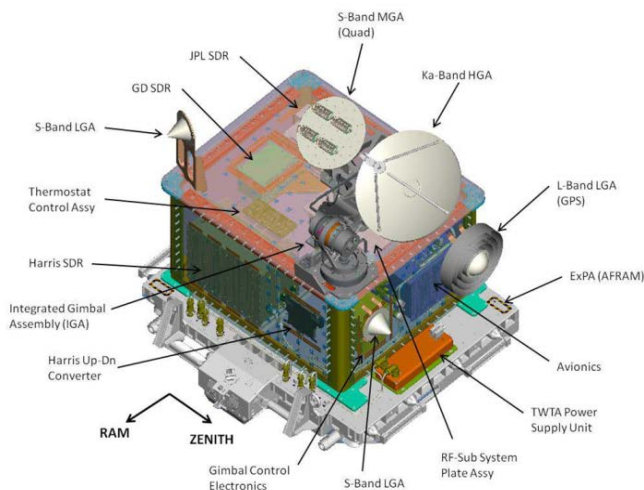


Figure 3: SCAN Testbed, ExPA, Radios and Infrastructure

Because of the nature of the MOU with the ISS, the configuration as depicted in Figure 3, was only applicable to the following system level tests: Thermal/Vacuum (TVAC) testing, Electromagnetic Interference/Electromagnetic Compatibility (EMI/EMC) testing, and later portions of Tracking and Data Relay Satellite System (TDRSS) Compatibility testing. The ExPA had already undergone System level vibration testing and retesting it integrated to the SCA<sub>n</sub> Testbed was not allowed per the MOU.

#### 3.1 Vibration Testing

System level vibration testing assessed the structural integrity of the Flight System and provided the appropriate data to verify through a combination of testing and follow-on analysis that the appropriate ground handling, launch, and on-orbit structural requirements were met.

#### 3.2 Thermal/Vacuum Testing

The primary purpose of system level thermal vacuum test was to verify aspects of the flight hardware function, stimulate latent hardware defects, validate the thermal model and the test provided the opportunity to characterize the system performance at simulated on-orbit environmental conditions. TVAC testing imposed environmental stresses upon the flight system in order to demonstrate design robustness and workmanship integrity over the maximum system level thermal design conditions. The test was designed to detect flaws in system level design, parts, processes, and workmanship.

#### 3.3 ElectroMagnetic Interference / ElectroMagnetic Compatibility Testing

The purpose of system level EMI-EMC testing was to demonstrate that the flight system was operationally compatible with applicable electrical power sources and electromagnetic environments of the H-II Transfer Vehicle (HTV) and International Space Station (ISS).

#### 3.4 TDRSS Compatibility Testing

Compatibility testing provided a means of verifying the compatibility of the SCA<sub>n</sub> Testbed's communications infrastructure with the service infrastructure provided by NASA's Space Network (SN) and Near Earth Network (NEN). This testing verifies that the new user will not harm SN or NEN communications assets and / or interfere with other users (excessive power levels, frequency drift, etc.).

### 4 RELIABILITY ANALYSIS

The reliability analysis that was performed for the AI&T phase of the CoNNeCT project was focused on the GSE and consisted of FMEAs, PHA, and parts quality searches. The parts quality searches employed 2 databases to ensure that no suspect parts were incorporated into the supporting equipment. The 2 databases were GIDEP (Government-Industry Data Exchange Program) for aerospace heritage,[2] and CPSC (Consumer Product Safety Commission) for commercial heritage. The FMEA's format followed the NASA GRC Work Instruction, GLWI-QE-8720.2.[3]

#### 4.1 GSE System Block Diagrams

System block diagrams representing the particular GSE system being certified to be interfaced to the flight system were used extensively. As an example, Figure 4 shows a simple system block diagram for a GPS test of the JPL SDR.



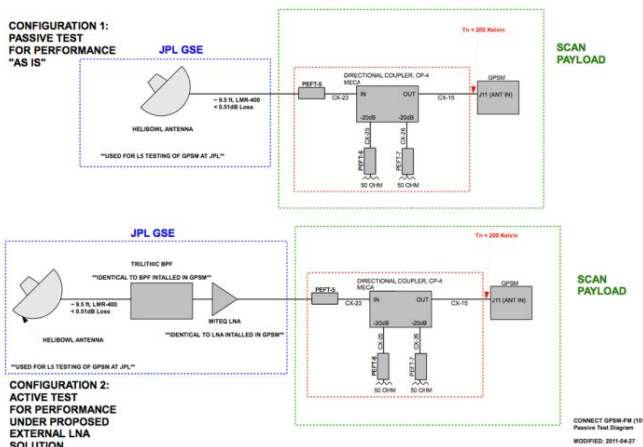


Figure 4: GSE Block Diagram for a GPS test on JPL SDR

Note that specific proprietary or limited distribution performance data has been edited out of the original system block diagram for this paper. These diagrams were used to feed the analyzes for the FMEAs and PHAs, with the actual blueprints and drawings serving as backups for more detail. Because of the dynamic nature of the SCA<sub>N</sub> Testbed test and verification program, maintenance of currency and relevancy of the specific diagram was not a trivial task. Further details are provided in the Configuration Management section below.

#### 4.2 FMEAs

Perhaps the best example of the GSE certification activities working to protect the Flight System was when a Failure Modes and Effects Analysis for the Ka-Band Tracking and Data Relay Satellite Simulator (TSIM) revealed that a potentially unacceptable problem existed. This caused the project's SMA Lead and Chief Engineer to hold off on approving the Certification of the GSE until corrective action was taken to fix this potential hazard. An FMEA update was performed to account for the addition of a Diplexer Circuit

ID	Subsystem	Signal Name/Conn/Pin	I/O	Function/Signal Characteristics	Failure Mode	Failure Causes	Failure Effects	Criticality	Mitigation
1	Diplexer Circuit	Return Link Rx	I	Path for attenuated TWTA output signal to Down Converter	Reflection of Return Link signal	Load mismatch from open/shorted connectors in Return Link path	Loss of transmission of TWTA output signal to the TSIM. Reflected signal will be attenuated by 60 dB in Ka-Band RF Load Circuit and will not damage the Harris SDR LNA (overload of LNA possible)	3	Inspection, acceptance test
2	Diplexer Circuit	Forward Link Tx	O	Path for combined Up Converter output signal and injected RF interferer signal to Harris SDR LNA	Excess signal power from Up Converter	Malfunction or incorrect adjustment of Up Converter	Possible damage to or overloading of LNA	3	Confirm maximum output power < -31 dBm
3	Diplexer Circuit	Forward Link Tx	O	Path for combined Up Converter output signal and injected RF interferer signal to Harris SDR LNA	Excess injected RF interferer signal	Malfunction or incorrect adjustment of signal generator	Possible damage to or overloading of LNA	3	Limit/monitor output of signal generator
4	Diplexer Circuit	Forward Link Tx	O	Path for combined Up Converter output signal and injected RF interferer signal to Harris SDR LNA	Output connector, open or shorted	Damage to connector, poor workmanship	Loss of transmission of TSIM signal to Harris SDR	3	Visual inspection

Table 1: Ka-Band TSIM FMEA

and use of the Ka-Band TSIM with a Ka-Band Radio Frequency Load Circuit. The short FMEA sheet is shown in

Table 1 below.

A failure mode was identified that potentially could burn up the Harris LNA (Low Noise Amplifier) if the input signal from the Up Converter and RF signal generator exceeded -31 dBm. Because this was a modification to an existing GSE configuration and FMEA, the potential hazard would have been easy to overlook had a new Failure Modes and Effects Analysis not been performed. modifications to the GSE (via "redlining" of test procedures, and the placement of warning stickers to protect the flight hardware) before being interfaced to the Flight System

#### 5 SYSTEM SAFETY

For every use of GSE interfaced to the flight system, a hazards analysis was performed to ensure that no significant hazards existed, not just to the flight system, but to the facility and personnel working with the GSE and flight system. The more complex installations and applications necessitate the use of a formal Preliminary Hazards Analysis (PHA). Table 2 presents a snippet of the PHA performed for the same Ka-Band TSIM with a Load Circuit presented in the Table 1 FMEA. Hazards analyzed were: collision, contamination of the workplace, corrosion, electric shock and electric damage, explosion, fire, temperature extremes, radiation, injury/illness, and loss of capability to the flight system. These hazards were specifically picked to satisfy NASA requirements.

FLIGHT PRELIMINARY HAZARD ANALYSIS					
Program: Communications, Navigation, and Networking reConfigurable Testbed (CoNNeCT), RF Load Circuit					
Engineer: John Britzman					
Item	Hazard Category Description	Affected Systems	Cause	Effect	Hazard Level / Assessment
1.0 Collision: Hazards which occur when GSE elements fail, break loose, or are allowed to make uncontrolled contact with other elements, typically resulting in the propagation of health risk to personnel.					
1.1	Collision	Entire GSE assembly	Handling during installation, changeout, and/or transportation.	Personnel injury. Damage to equipment.	Level: Review of material usage by GRC M&P. Fan contained within housing and two finger guards.
1.2	Collision	Cooling fan	Failure of motorized systems.	Personnel injury. Damage to equipment.	Level: Fan will not be operated outside of acceptable range. Review of material usage by GRC M&P. Fan contained within housing and two finger guards.
2.0 Contamination of Workspace: Release of toxic, flammable, oxygen-depleting, corrosive, condensable, or particulate matter into the workspace where the GSE will be utilized. Not Applicable. No contamination hazard exists.					
3.0 Corrosion: The structural degradation of metallic and nonmetallic equipment, possibly resulting from leakage of caustic/corrosive materials, joining of dissimilar metals or erosion. Not Applicable. No sources of corrosion.					
4.0 Electric Shock and Electric Damage: Personnel injury or fatality and/or adverse effect on performance and operation of equipment because of contact with a live circuit, either intentional or inadvertent. Not Applicable. No sources of electric shock or electric damage.					

Table 2: Ka-Band TSIM PHA

#### 6 CONFIGURATION MANAGEMENT

In order to keep the flight payload protected from damage due to the inevitable changes and additions to equipment that occur during integration and testing, good Configuration Management (CM) was maintained. The certification package that was entered into the CoNNeCT Configuration Management System was modified by the cognizant engineer. This may have included new drawings, diagrams, Hazard Analysis, FMEAs, and acceptance tests, as appropriate. The package was then resubmitted to the SCA<sub>N</sub> Testbed's Chief Engineer and SMA Lead for review and comments. Once concurred and accepted, the modification to the original package was released and filed in the project's electronic

document tracking and distribution CM system.

#### REFERENCES

1. "Standard For The Design And Fabrication Of Ground Support Equipment," NASA-STD-5005C.
2. "Procedures for Exchanging Parts, Materials, and Safety Problem Data Utilizing the Government -Industry Data Exchange Program and NASA Advisories", NASA NPG 8735.1.
3. "Failure Modes and Effects Analysis (FMEA), Critical Items List (CIL), and Fault Tree Analysis (FTA)," GLWI-QE-8720.2.

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Mr. Riddlebaugh earned his BS degree in Electrical Engineering from the University of Michigan and MS degree in Electrical Engineering from the Ohio State University. From 1974 to 1987 he did electronic development and design work for RCA Corp., Gould Inc., and Goodyear Aerospace Corp. Since 1987 he has provided Safety and Mission Assurance Engineering support to the NASA Glenn Research Center while employed by Analex Corp., Raytheon Corp., Science Applications International Corp., and ARES Corp. His work during this period has been primarily in the

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John is a graduate of Indiana University of Pennsylvania (IUP) with a B.S. in Safety Sciences. He currently works for ARES Corporation supporting the NASA Glenn Research Center (GRC) Program and Project Assurance Division (PPAD) performing systems safety engineering on a variety of projects. For the CoNNeCT Project, John serves as the ground/launch safety engineer. From 2000-2005, John was the contractor system safety lead for the Fluids and Combustion Facility (FCF) and provided payload systems safety engineering support for the development of the following FCF payloads that are currently operational on the International Space Station (ISS). Prior to his current assignment, John supported the NASA Safety Center by: managing the content of the NASA Process Based Mission Assurance – Knowledge Management System (PBMA-KMS), supporting the Mishap Investigation Support Office (MISO) and, supporting the Technical Excellence Office (TEO) in the development of a training curriculum for NASA Systems Safety Engineers. John has also spent significant time supporting the GRC Safety, Health and Environmental Division (SHED).

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Myron Wilkinson has 19 years experience as an M&P Engineer at NASA GRC on such programs as the Space Station Electrical Power System, microgravity experiments (Shuttle, ISS, and Mir), ISS Fluids & Combustion Facility, Constellation, and CoNNeCT. Other experience includes seven years as a Quality Engineer in the defense industry, working with aircraft landing gear and U.S. Navy nuclear propulsion systems. Myron attended the University of Akron, majoring in Mechanical Engineering Technology.